Machine Protection Needs in ERLs

Lars Fröhlich

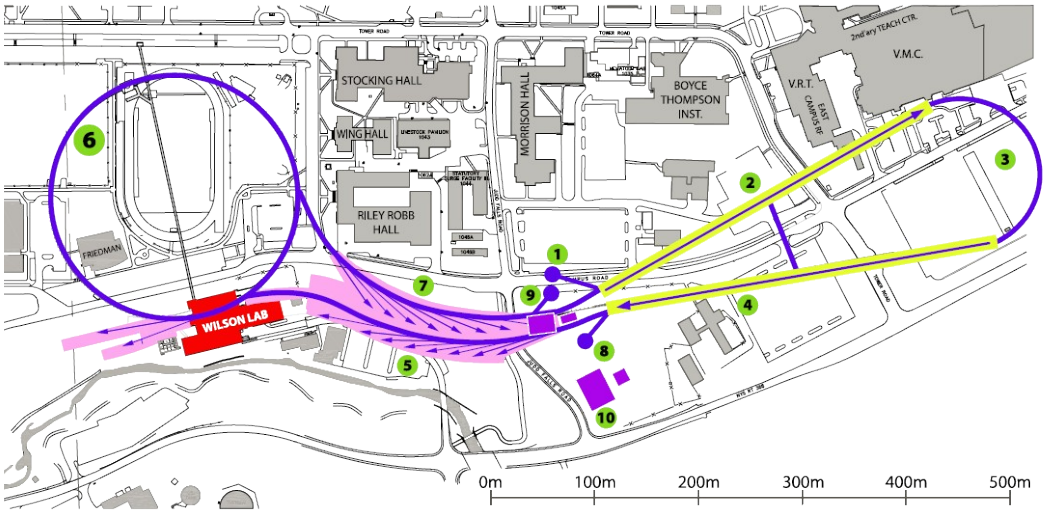
ERL'09 — June 8, 2009

Peculiarities of ERLs

- **High average beam power:**
  100 mA · 5 GeV/e = 500 MW

- **In case of strong losses:**
  Breakdown of energy recovery
  → maximum loss power determined by capacity of RF system

- **In case of small losses:**
  Tiny fraction of the beam
  still carries huge average power

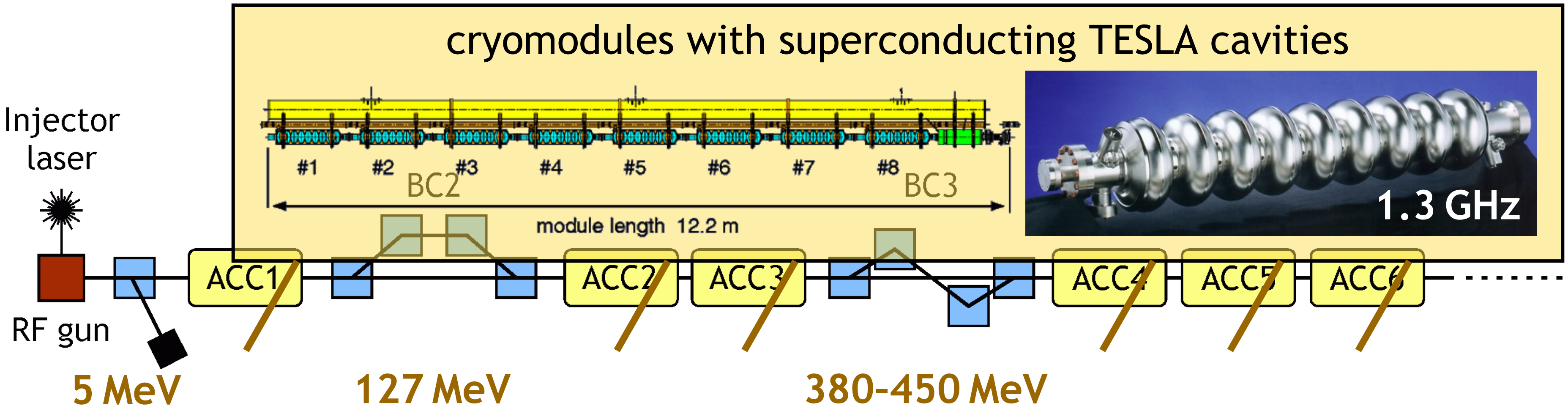


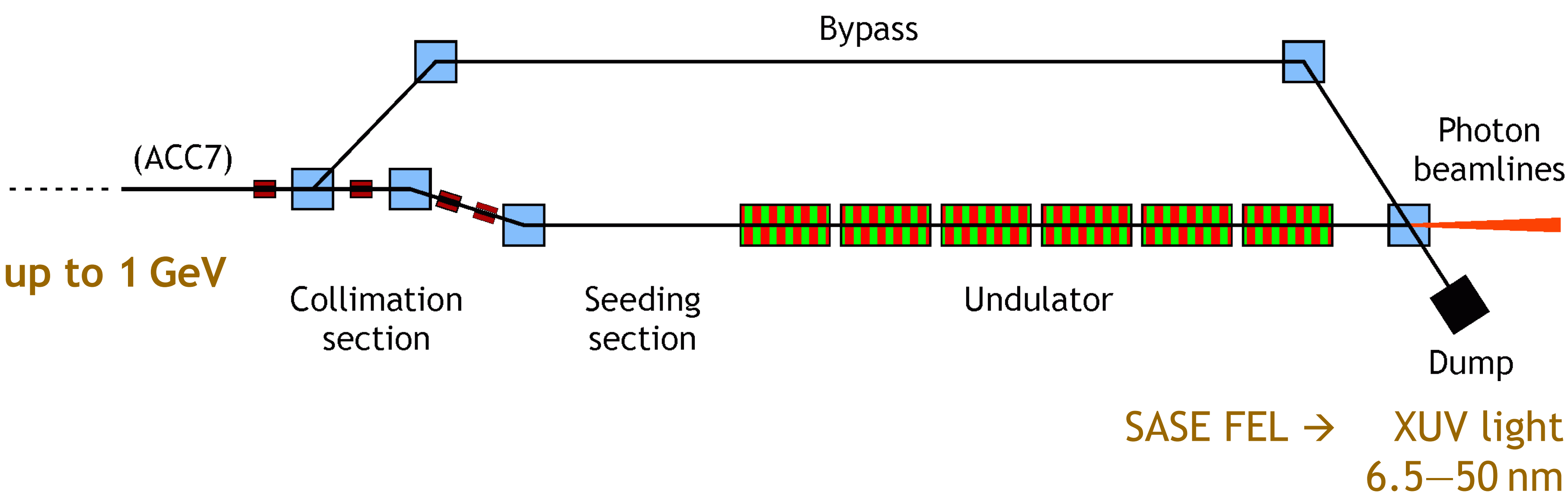
For an ERL with **P = 100 MW**:

Local loss power (W)	Effects
0.001 — 0.1 10^{-11}	Demagnetization of permanent magnets
1 — 10	Excessive cryogenic load, quenches
1 — 100	Radiation damage to electronics, optical components, &c.
1 — 100	Radioactivation of components
10 — 100	Mechanical failure of flange connections
100 — 1000 10^{-5}	Other thermal effects, mechanical damage

Local loss power (W)	Effects
0.001 – 0.1	Demagnetization of permanent magnets
1 – 10	Excessive cryogenic load, quenches
1 – 100	Radiation damage to electronics, optical components, &c.
1 – 100	Radioactivation of components
10 – 100	Mechanical failure of flange connections
100 – 1000	Other thermal effects, mechanical damage

FLASH — Not an ERL...

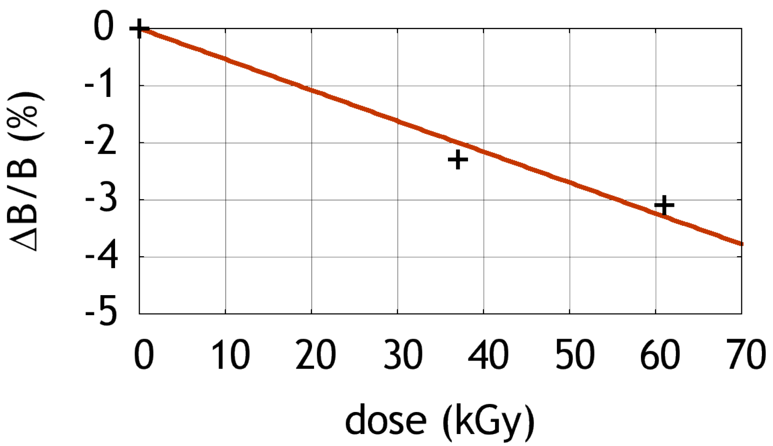




Measurements at FLASH

- Relative demagnetization: **$5 \cdot 10^{-7}$/Gy**

	Dose (kGy)	ΔB/B (%)
2004-08-13	0	0
2006-03-21	37	−2.3
2007-09-29	61	−3.1



Simulations indicate

10% FEL power loss

for

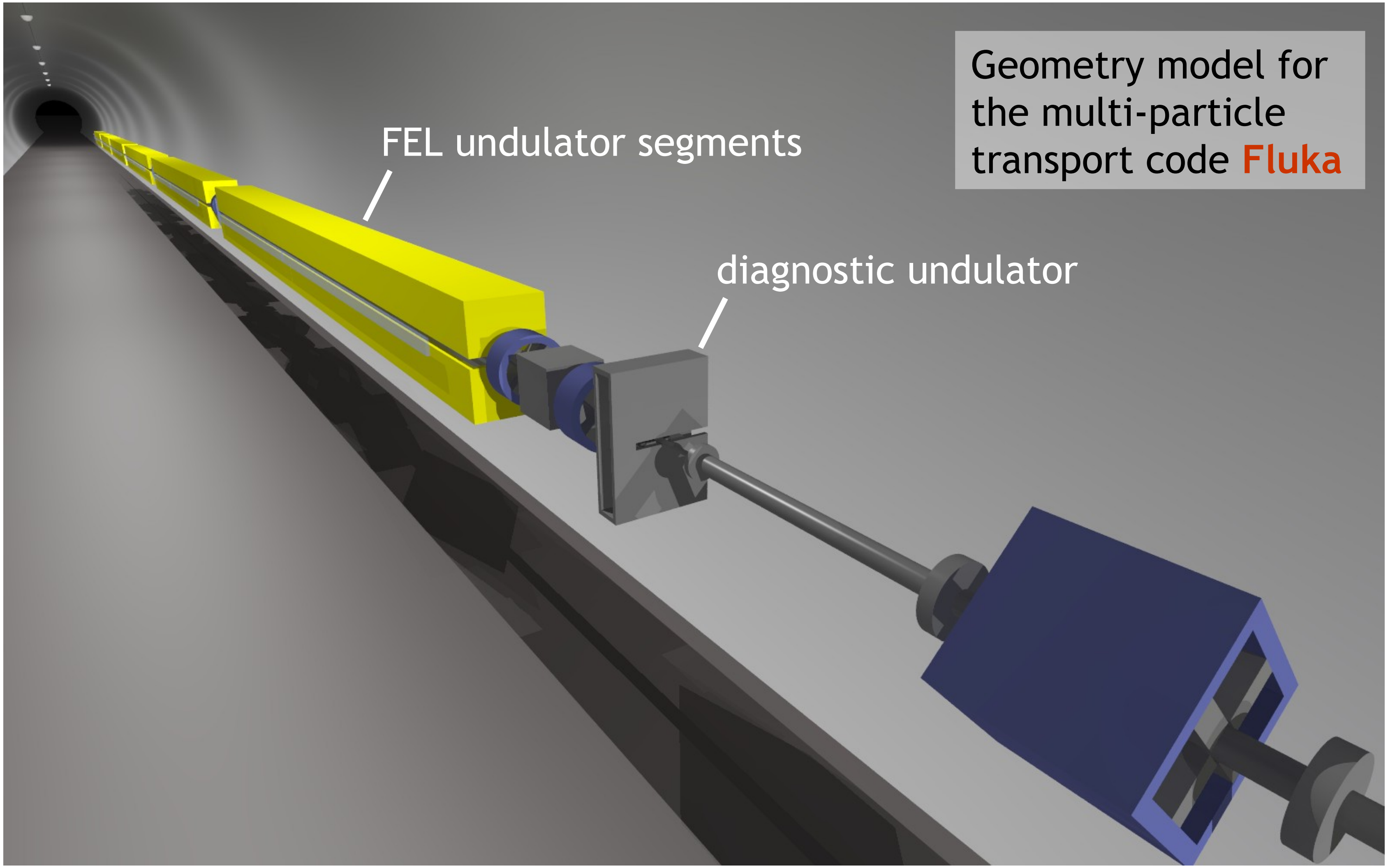
0.5% (periodic) field loss

For 10 years undulator lifetime:

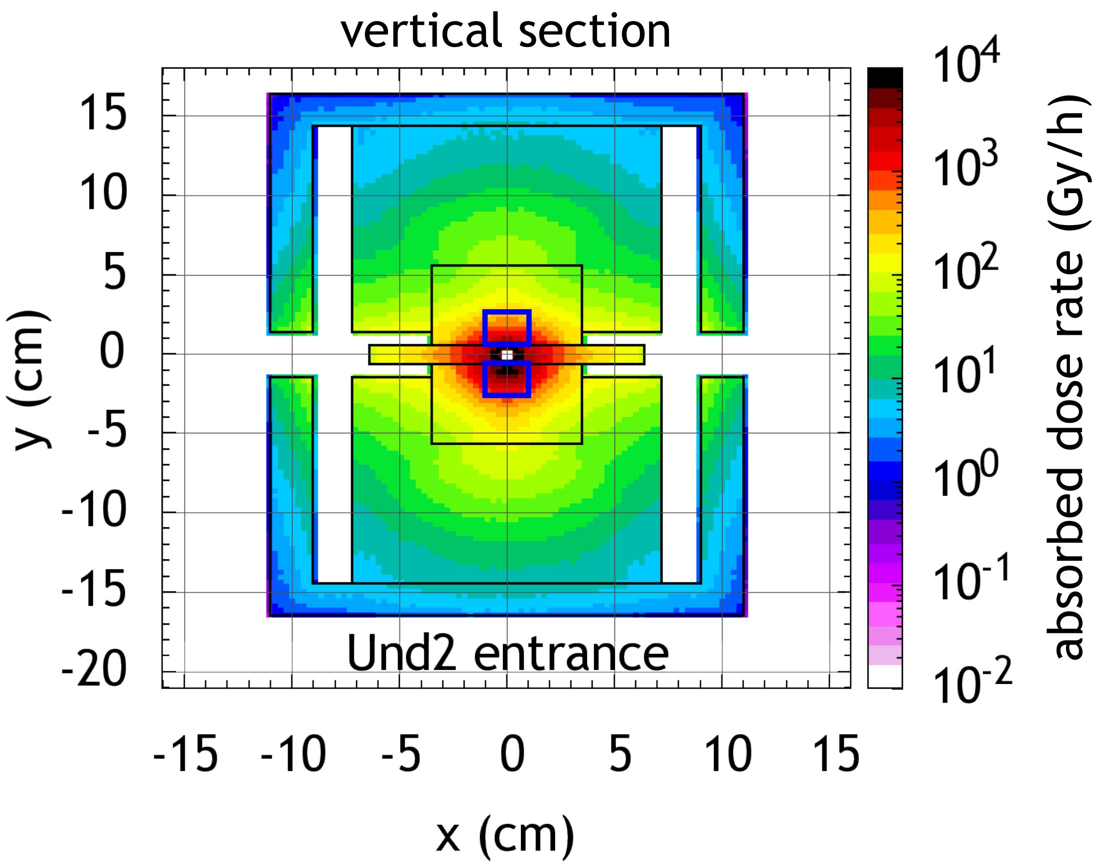
5 Gy/d dose budget

Skupin, Li, Pflüger, Faatz: Undulator demagnetization due to radiation losses at FLASH, *Proc. EPAC 2008*, pp. 2308–2310

Undulator Beamline Model



Geometry model for the multi-particle transport code **Fluka**

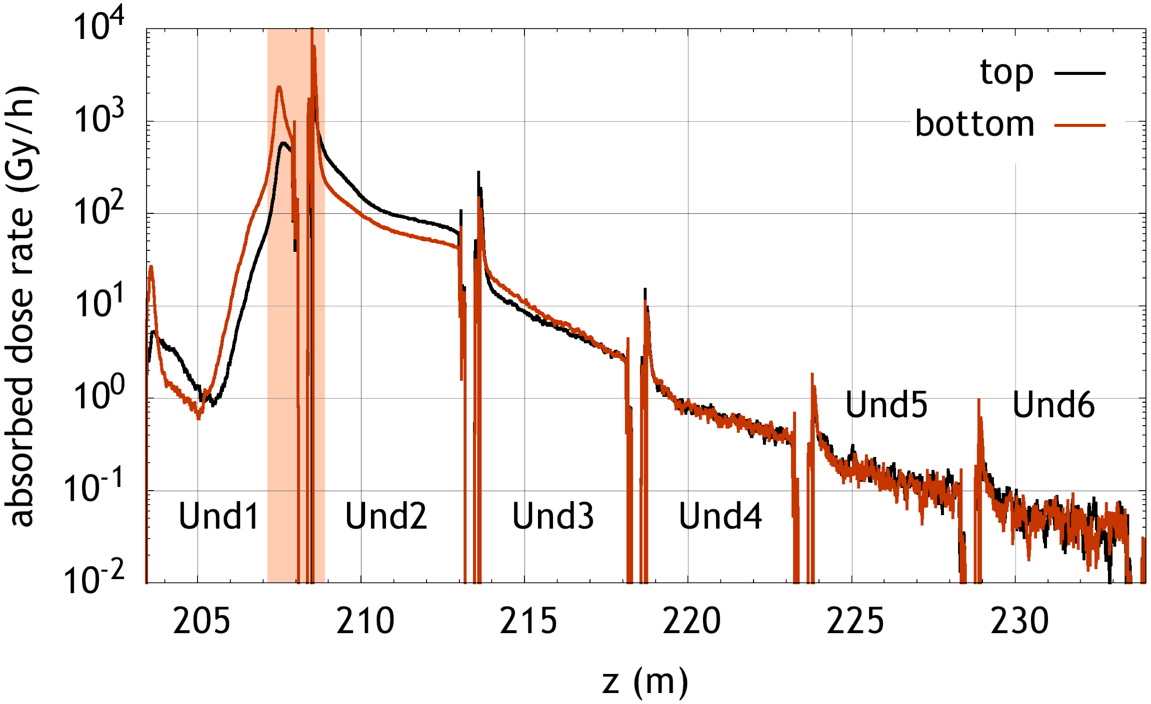


- Loss of a bunch at the exit of undulator 1
- Bunch strikes the bottom of the vacuum chamber

Parameters:

- 1 GeV
- 1 nC/bunch
- 1 bunch/macropulse
- 10 Hz

Beam Loss in the Undulator



- Dose rate around **1 kGy/h** in an extended range (1 nC/bunch, 10 Hz, 1 GeV → **10 W**)

To stay within 5 Gy/d, local beam loss has to be limited to **2 mW.**

For a 100 MW beam:

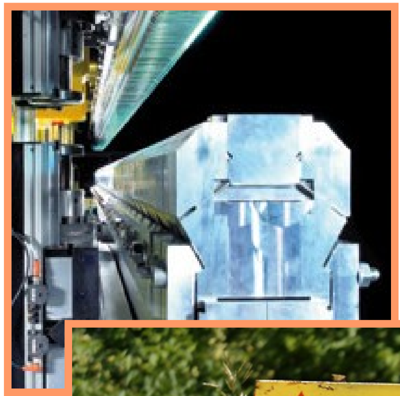
$2 \cdot 10^{-11}$ (relative)

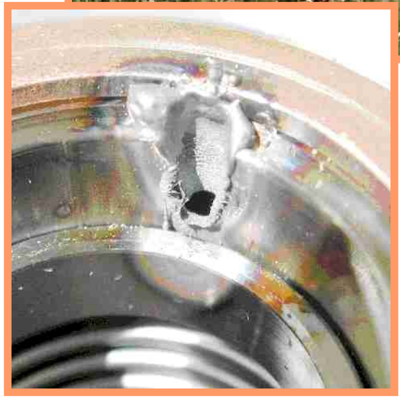
For CW 1.3 GHz beam:

<10 MeV/bunch

Hazards

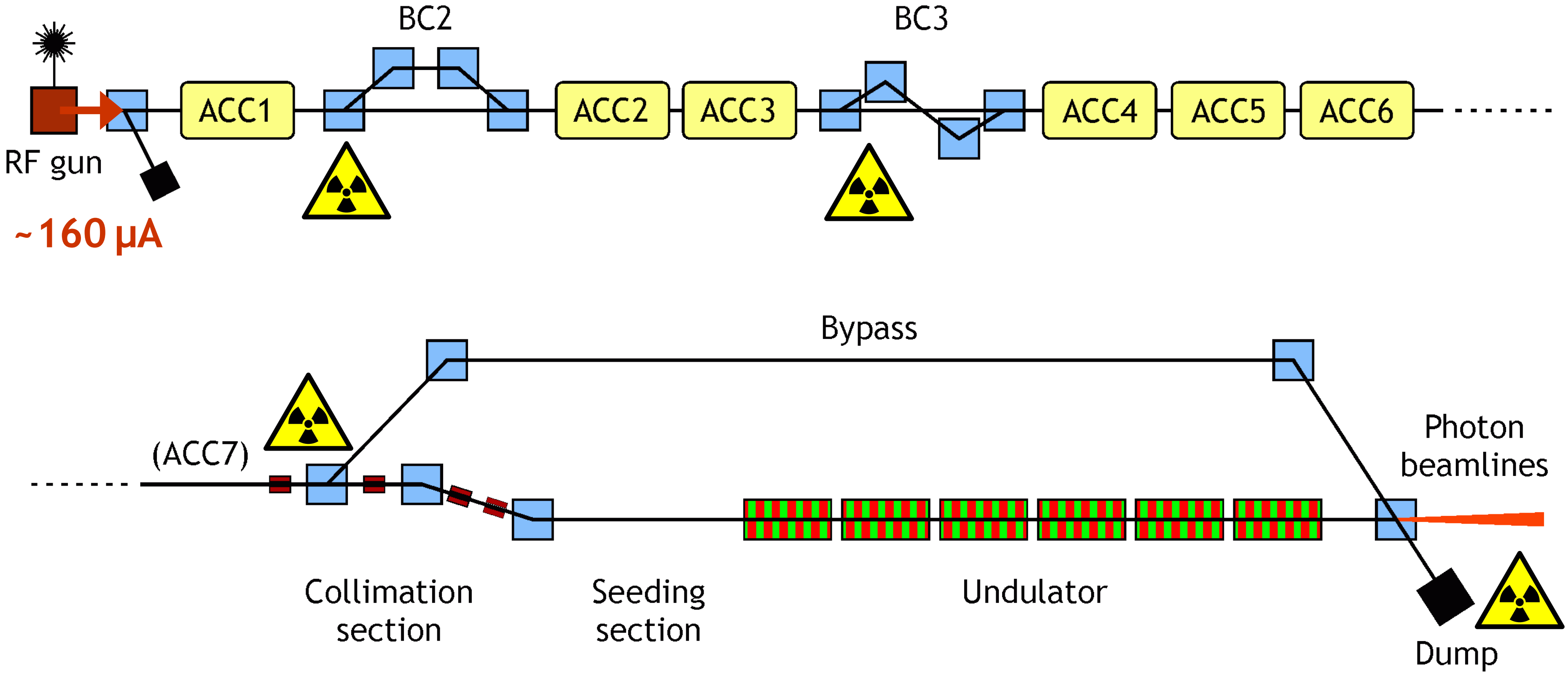
Local loss power (W)	Effects
0.001 – 0.1	Demagnetization of permanent magnets
1 – 10	Excessive cryogenic load, quenches
1 – 100	Radiation damage to electronics, optical components, &c.
1 – 100	Radioactivation of components
10 – 100	Mechanical failure of flange connections
100 – 1000	Other thermal effects, mechanical damage





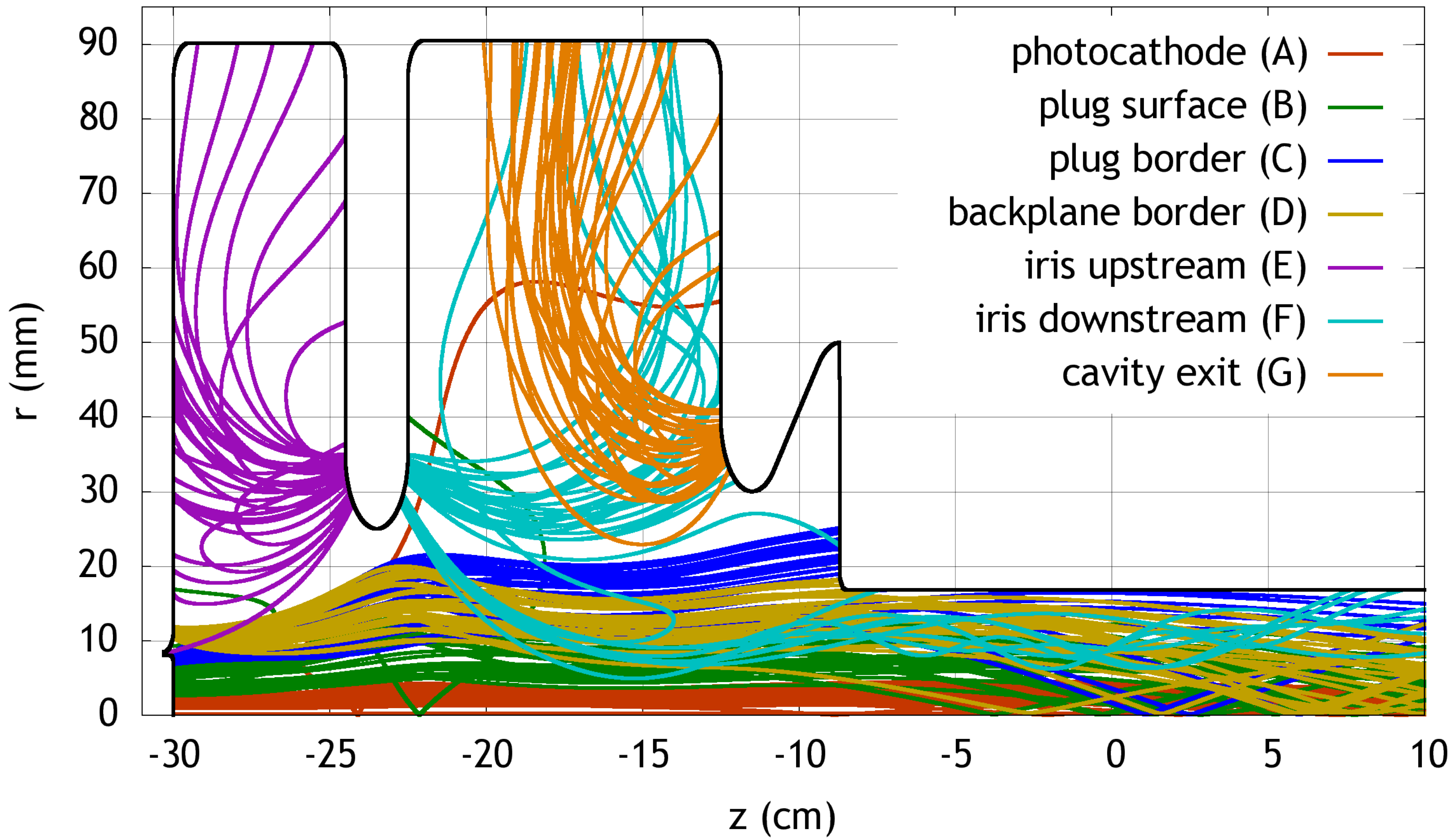
Activation of Components at FLASH

Main source at FLASH:
field emission from
RF gun

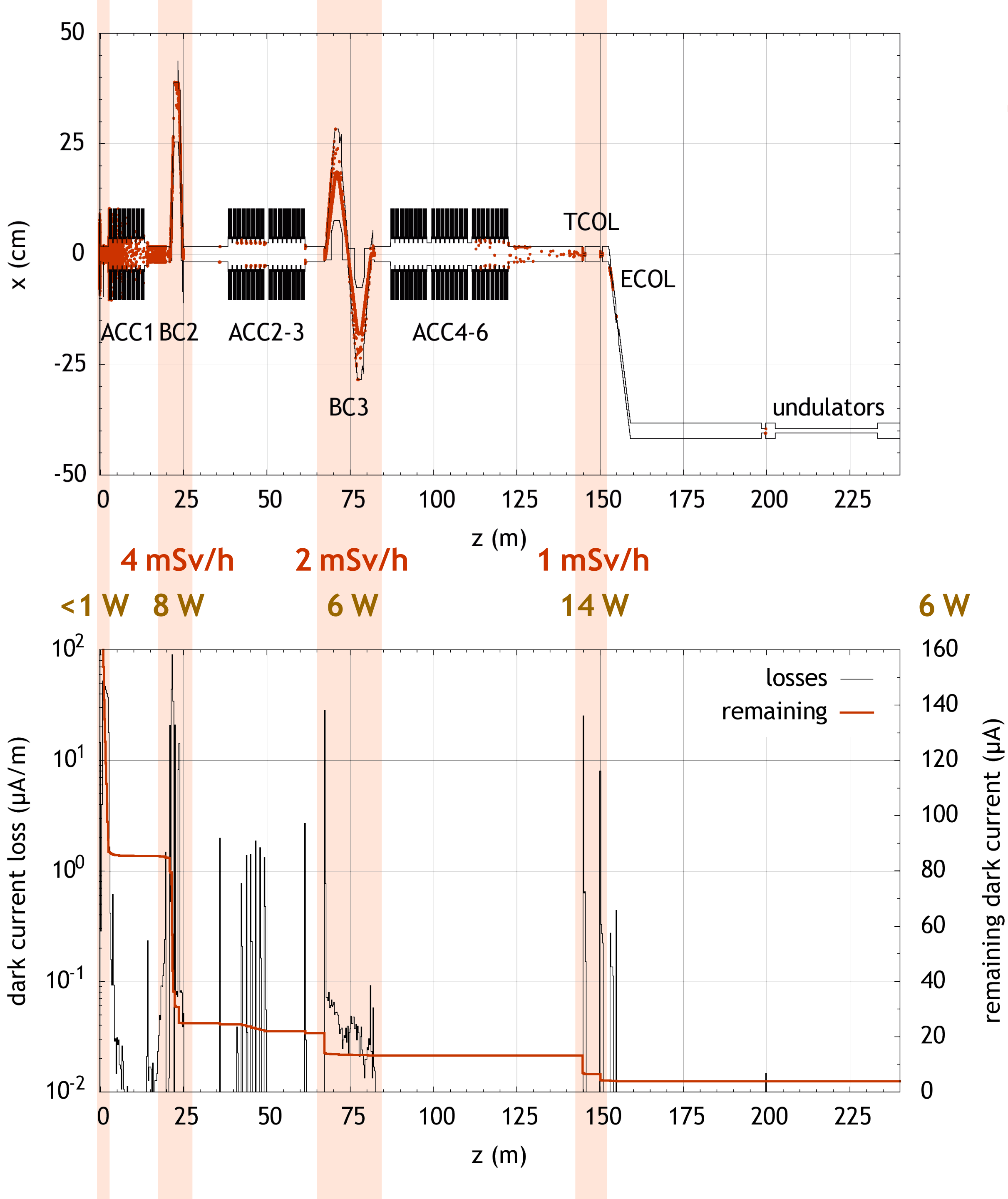


Dark Current Transport in the RF Gun Cavity

Tracking of dark current from emitter surfaces
(with enhanced **Astra** code for complex 3D geometries)



Overview



Location of major dark current losses:

- behind rf gun
- bunch compressor 2
- bunch compressor 3
- transverse collimators

contact dose equivalent rate

dark current power deposition

For 100 MW ERL: relative beam loss of **10^{-7}** can cause significant activation problems

Machine Protection Needs

for high power ERLs

Passive Protection Needs

Very good understanding and control of beam dynamics:

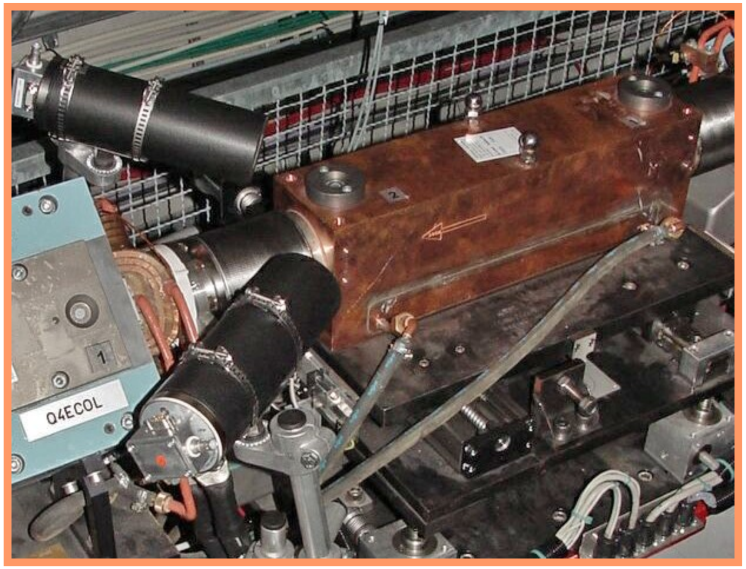
- matching
- halo formation
- space charge, CSR, Touschek scattering, gas scattering, ion trapping, BBU
- dark current sources & transport

Very good collimation & shielding:

- at energies as low as possible
- after halo sources
- special attention: cryo sections, insertion devices (esp. long ID sections)

What may help:

- large apertures
- exchangeable insertion devices



Machine Protection System Needs

Preventive measures

- Check magnet currents, RF systems, water flow, &c.
- Define valid beam paths (operation modes, machine modes)
- Define power limits (beam modes)

Fast beam interlock

- As fast as possible: microseconds (cable delays)
- Actuators:
  - injector laser
  - RF power
  - dump kickers (for long machines)
- Inputs:
  - Systems for beam loss detection
  - BPMs
  - Quench detection for SC cavities

Differential current monitoring

- DCCT setup proposed at BNL aims at $5{\cdot}10^{-4}$ resolution

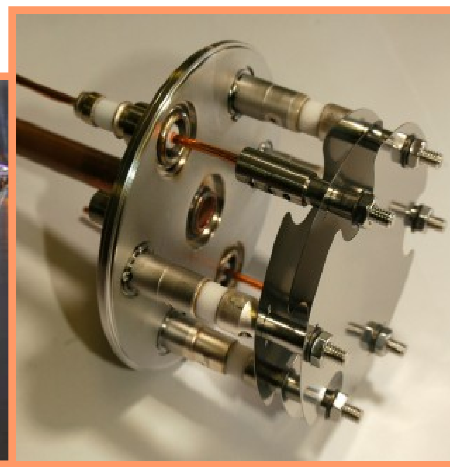
P. Cameron, Differential Current Measurement in the BNL Energy Recovery Linac Test Facility, Nucl. Instr. and Meth. A 557 (2006), pp. 331—333

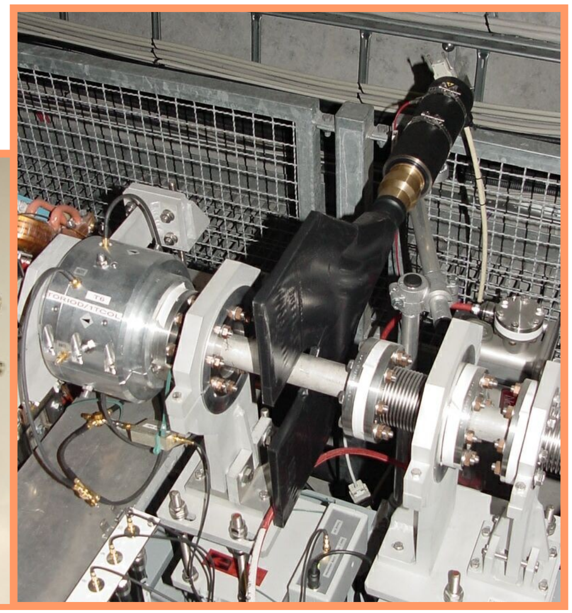
Beam loss monitors

- wide range of photomultiplier-based designs
- discrete ionization chambers

} well suited for ID protection

- long ionization chambers (gas-filled coax cables)
- PIN diodes
- secondary electron monitors





Thanks for your attention.